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Small Anode Source for Efficient Ion Production

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Ion source modification is proposed for efficient production of ion beam and extending of operating lifetime. Ionization efficiency of the Bernas type ion source has been improved by using a small anode- thin rod, oriented along the magnetic field. Transverse electric field of small anode transport plasma by drift in crossed field to the emission slit. Optimization of the cathode material recycling is used to increase the operating lifetime. Optimization of the wall potential used for suppression of flakes formation. Three- electrode extraction system was optimized for low energy beam production and efficient space charge neutralization. Ion beam with emission current density up to 60 mA/cm^2 has been extracted from discharge in BF$_3$ gas. Ion beams of ^{11}B isotope with intensity up to 6 mA for 3 keV, up to 11 mA for 5 keV, 18 mA for 15 keV have been transported through the analyzer magnet.

I. INTRODUCTION

Reviews of ion sources development for ion implantation and isotope separation have been presented in [1,2,3]. The Bernas-White ion source (BWIS) with a hot cathode arc discharge in the weak magnetic field is the primary source use at present for high current ion implanters and several versions of the BWIS manufactured by some industrial companies. Advanced versions of the BWIS with two filaments or indirectly heated cathodes used for high current and

multicharged ion beam production [4,5]. Further improvement of ion beam parameters and increase of the ion source lifetime is necessary for advanced ion implanters.

II. CONFIGURATION OF SMALL ANODE SOURCE

With hope to improve the efficiency of ion beam production and to increase operating lifetime a new version of ion source- ion source with small anode (Small Anode Source- SAS) has been developed and tested in beam lines of several implanters. Design of the SAS is shown on Fig. 1. This version of ion source is close to the BWIS and could be assembled from the industrially available parts. BWIS could be easily converted into the SAS by modification of the standard source parts. In the BWIS gas discharge in longitudinal magnetic field up to 0.3 kGauss between a hot filament- cathode (1) and discharge chamber walls- anode (2) is used for ion production.

In the Small Anode Source (SAS) additional small, insulated electrode (7) is inserted into the discharge chamber and the current between hot filaments- cathodes (1,4) and this small electrode- Small Anode (SA) (7) supports discharge. Discharge chamber (2) has floating potential close to the cathode potential and plasma has a potential close to that of the small anode. The axis of a small anode is parallel to the magnetic field lines (magnetically insulated) for suppression of electron mobility perpendicular to the magnetic field. It is important to have cross ExB fields plasma drift in the direction of the emission slit (3) as in ion source, discussed in [6]. In the BWIS, as in other Penning configurations, electrons have closed drift in the crossed field around the anode. Insertion of the anode (7) near one wall and transformation of the other walls to the cathode surface change the direction of the electric field and direction of the drift near one side of discharge chamber. In this SAS configuration all plasma should drift to the front plate with the emission slit (3), or to the base plate with gas tube, depending of the magnetic field

orientation. With drift to the emission slit it is possible to have a high extracted current with a small discharge current and voltage. With the opposite drift direction much higher arc current is needed for the same extraction current, but the level of molecular ions dissociation should be higher, because arc current is higher. The SAS can operate with the filaments connected with a chamber wall (with metal deposited filaments insulators). By connection of SA to the chamber wall the SAS is transformed to the BWIS with close drift of plasma around the anode walls.

III. EXTRACTION SYSTEM

Three- electrode extraction system has been optimized using computer simulation. The calculation and optimization of extraction geometry were made using the relaxation code PBGUNS [7]. This code, which has been well tested, simultaneously relaxes the shape of the meniscus at the plasma boundary to include the effects of plasma density together with the effects of space charge within the beam as the extracted ions accelerate through the extraction region. Space charge neutralization at the level of 0% to 100 % is assumed beyond the suppresser electrode.

The assumptions underlying the above calculations are that the source is operating using BF_3 gas, and that approximately 20% of the ions leaving the source are B^+. Fig. 2 is the sketch of geometry near the extraction region with ray diagram of the ion envelope at right angles to the length of the extraction slit. For the energy of 3 keV an optimized geometry could be found that allows to achieve an emission current density of j=60 mA/ cm^2 into an angle of $\alpha \sim 50$ mrad, accepted by the analyzer magnet of implanter. Emittance diagrams have been calculated at various distances downstream. It should be noted that these emittance plots are quite linear suggesting that source aberrations will not significantly increase the effective emittance of the

beam entering succeeding optical components. Beam deflection by differential voltage on suppression electrodes has been simulated.

A high suppression voltage (up to -20 kV) should be used for the production of low energy high perveance beam. With fixed gaps extractor system it was very difficult to keep low level of suppression electrode current for different extraction voltages. With the strong bombardment of extractor electrodes by ions overheating and sputtering of extractor electrodes occurs. For overcoming these problems fine moving manipulator of extractor/ suppression electrodes was developed. Manipulator can move a suppresser- grounded extractor assembly along the beam and in a perpendicular horizontal direction with step up to 0.02 mm. Manipulator with developed software was used for optimization of the extraction gap, suppresser slit width, and slit horizontal position relative to emission slit. Tilt rotation was used for compensation of the extraction gap nonuniformity and a vertical beam steering. Horizontal slit moving and differential voltage on suppressor electrodes were used for the horizontal beam steering.

The extraction condition was significantly improved by the manipulator optimization. Minimization of suppression electrode current improved the operation stability, decrease a film deposition and flacks formation. Further some improvements of manipulator for increase of stability, repeatability and serviceability have place. High perveance beam is very sensitive to the extractor electrode position and often moving of one step of 0.02 mm can visible change beam intensity.

IV. TEST RESULTS

In the first test of the SAS a small anode, shown in Fig. 1 (7), was used. It was made from 2.4 mm diameter tungsten wire (as filaments) of 50 mm length along discharge chamber supported

by ceramic (filaments) insulators (8) in the middle part of the left side- wall of discharge chamber. From the first short started stable source operation and efficient beam generation. In the further experiments the SA supporting insulators were shielded by disks for prevention from deposition by filaments vapor. For improving a plasma's homogeneity along the slit the SA was increased up to 70 mm. Two relative positions of filaments and SA have been tested: filament down (far from front plate, 6mm distance) and filaments up (close to the front plate, 2mm distance); the SA position up (10mm from the front plate) and the SA down (15 mm from the front plate). For the mode filament up, the SA up an extraction current is 70 mA have delivered by arc discharge 2 A. With this arc current gas ion dissociation is relative low. This mode is not good for B^+ production, but could be good for BF_2^+ production. With a filament up, the SA down, emission slit 2.5x90 mm^2 was received good efficiency for B^+ with energy 10 keV. Analyzed beam of $^{11}B^+$ with current 10 mA and $^{10}B^+$, 2.5 mA, energy 10 keV was produced with arc current 3.5 A and arc voltage 98 V (extraction current is 61 mA). For low energy beam production and transportation is very important to suppress a heavy ion extraction along with atomic ion B^+. For deeper dissociation of molecular ions it is necessary to use high arc discharge current with not too high extraction current. For this it is necessary to suppress the efficiency of plasma delivery to the emission slit. SAS operation mode with filament down, SA down, corresponding a plasma generation far from emission slit, is better. In several runs with production of 10 mA, 10 keV boron beam behind an analyzer were reached a filaments lifetime T=100-120 hours.

To increase a source lifetime in the high arc current mode operation it is possible to use:

1. Operation with high arc current, but with low arc voltage (~10 A, 50-70 V).

2. Use filament with 2.5 turns instead of 1.5 turns of standard filaments.

3. Use tungsten parts of the arc discharge chamber or tungsten plates inserts for improved recycling of filament material by halogen cycle. Solid deposition of tungsten to the source walls and to the filament, keeping with a lower temperature, has been observed.

4. Optimize position, support and shape of the small anode and filament position for the improvement of molecular ion confinement in plasma and increase of molecular ion traveling time to the emission slit.

With the reversed direction of the source magnetic field (plasma drift out of emission slit, filaments up, SA down) for 10 keV, 4.7 A arc current, 96 V arc voltage, beam current was 5.2 mA with extraction current 33.5 mA.

For comparison, in close discharge condition in the BWIS with filaments down for 10 mA, 10 keV $^{11}B^+$ ion production was needs arc discharge current 7.09 A, voltage 99 V extraction current 75 mA (instead of 3.5 A, 98 V, 61 mA for SAS). In the BWIS mode with filaments up, for 8 mA, 10 keV, $^{11}B^+$ beam was delivered with arc current 3.7 A, voltage 114 V, extraction current 64 mA. Some general characteristics of small anode source are demonstrated in Fig. 3, were the current of $^{11}B^+$ ions behind analyzer versus arc discharge current is presented for different extraction voltages. Comparison of beam current, generated by SAS and BWIS for 10 keV energy is shown in Fig. 4. In the optimized versions of SAS, close to presented on Fig.1, 2 for production of any analyzed beam current it is enough up to 2 or 3 time less arc current than in the BWIS. An importance of plasma drift in the crossed field was tested by change of source magnetic field direction and by rotation of source to 180 degree around the horizontal axis. In both cases of plasma drift in opposite direction, for the same ion beam production the arc current should be increased approximately two times.

With close plasma drift is created favorite condition for development of the plasma parameters

oscillation. Inserting of the Small Anode is change the symmetry of plasma drift and change conditions for plasma instabilities. Some modes of the SAS discharge operation are very stable, and of beam intensity has a very low level of oscillations (in oscilloscope track noise level is 10 mV relative to 2V DC beam signal of 8 mA).

V. CONCLUSION

Small Anode Source (SAS) with a small, magnetoinsulated anode has been developed and tested. Improved efficiency of ion beam production has been demonstrated. Up to 18 mA of $^{11}B^+$ has been attained behind a mass analyzer. Low level of beam current oscillations has been demonstrated. Increased operation time has been demonstrated. Recycling of cathode material and solid deposition of cathode material without flakes formation has been observed.

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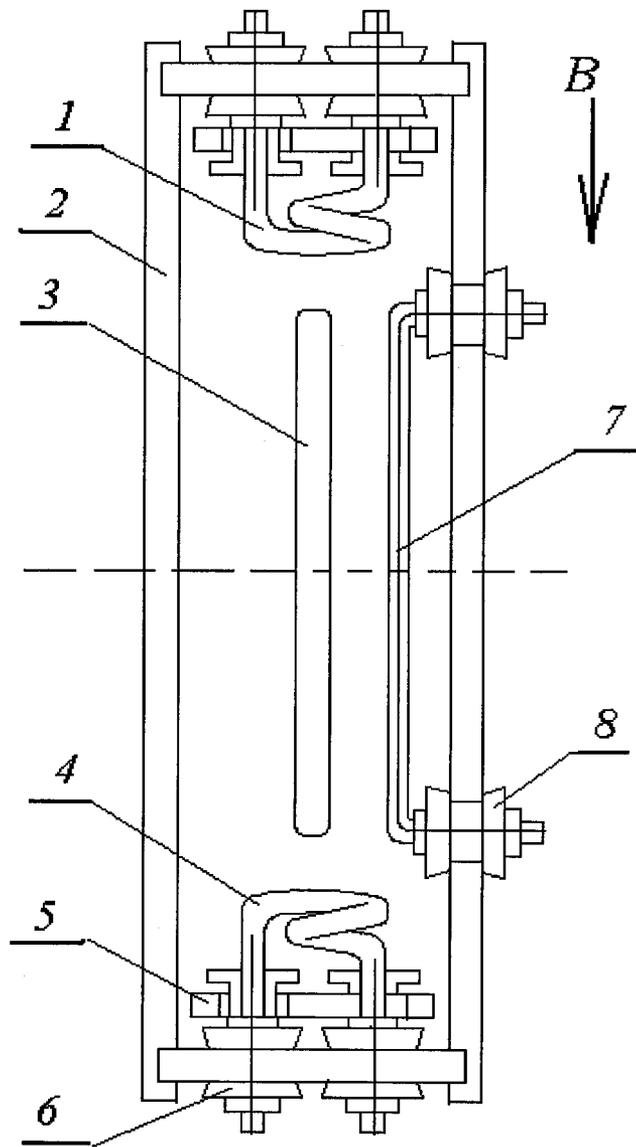
Fig. 1. Cross section of ion source with a small, magnetoinsulated anode (SAS)

1- cathode #1; 2- gas discharge chamber; 3- emission slit; 4- cathode #2; 5- cathode's reflector;

6- cathode's insulators; 7- anode; 8- anode's insulator.
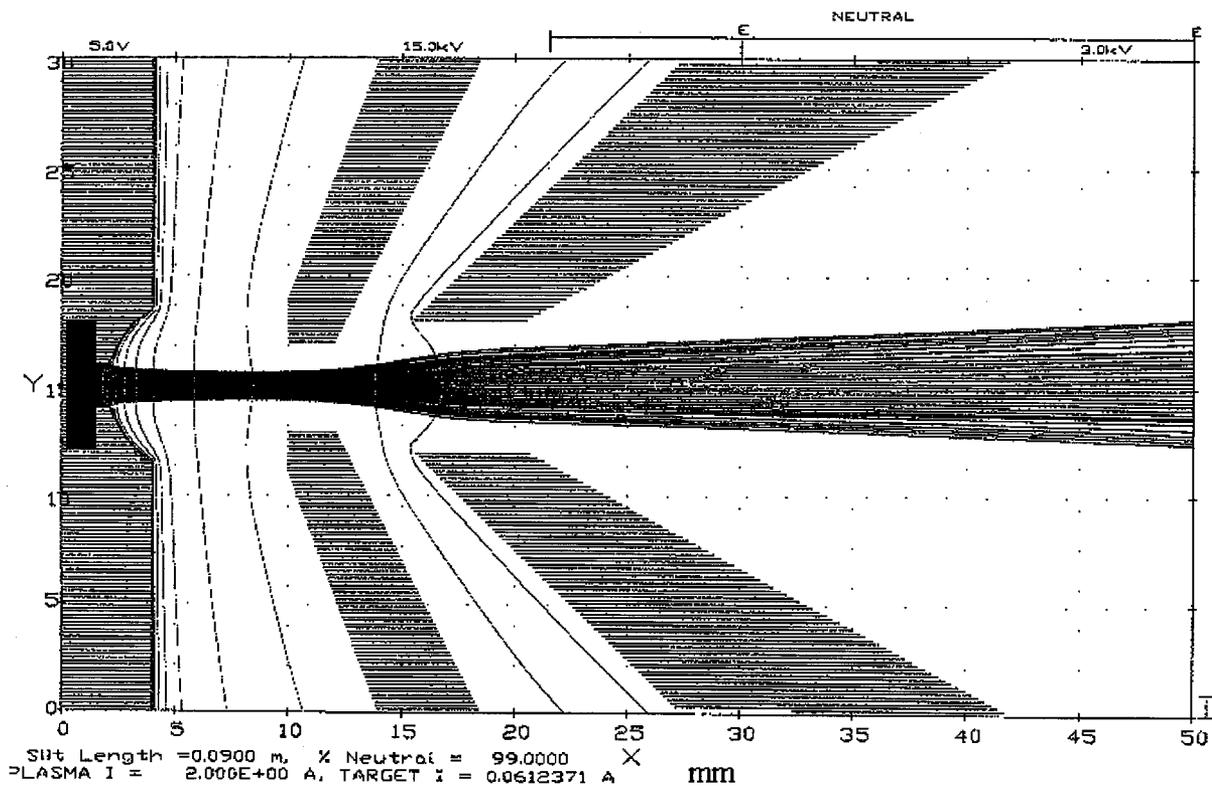
Fig.2. Schematic of three- electrode extraction system and low energy beam formation.
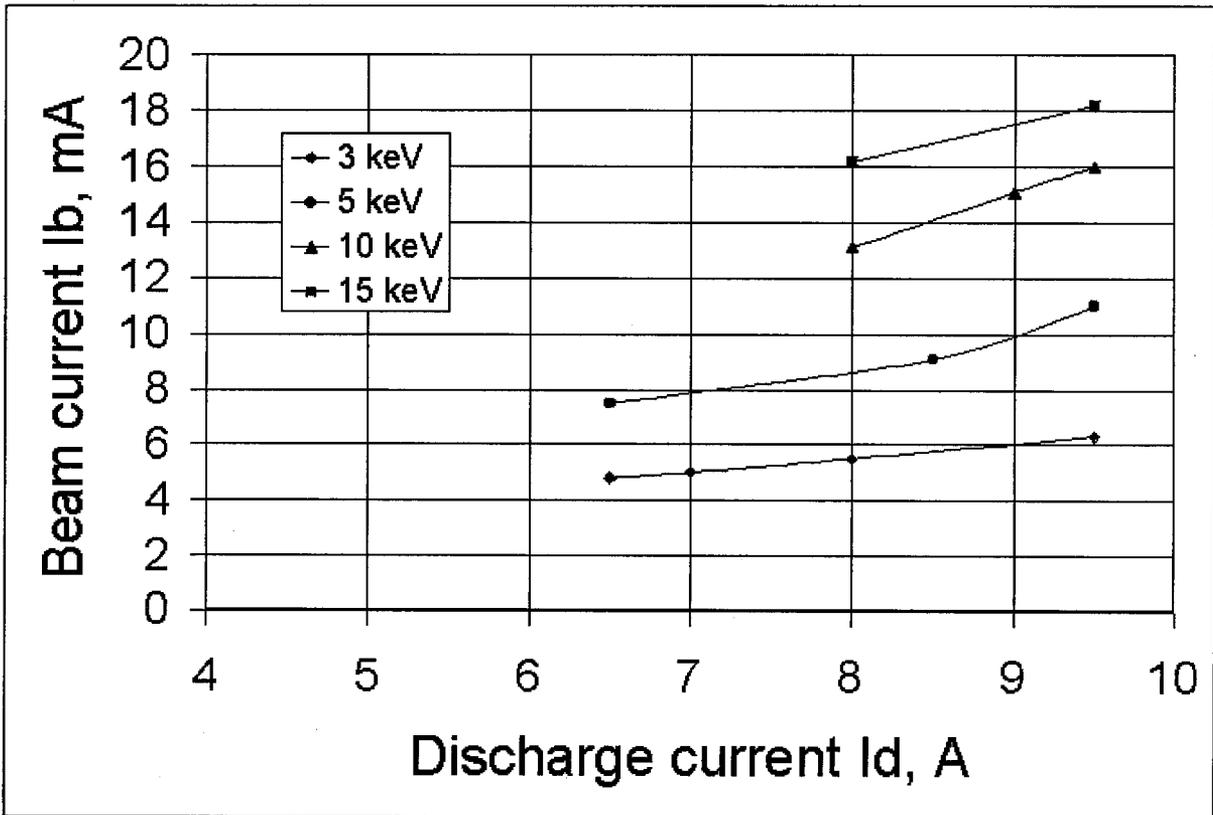
Fig. 3. Ion beam current behind analyzer vs discharge current in SAS for different ion energies
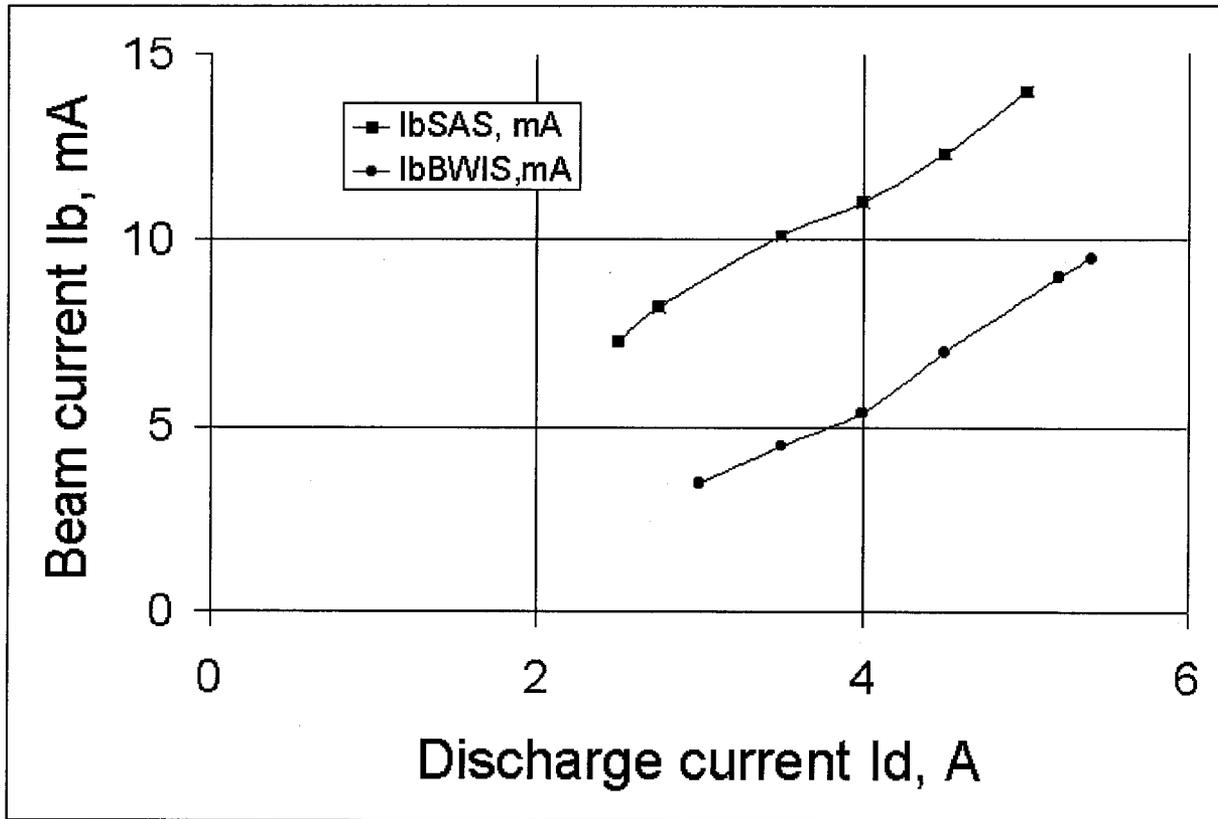
Fig. 4. Ion beam current behind analyzer vs discharge current for SAS and for BWIS.